Acoustic Seaglider™ for Beaked Whale Detection

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LONG-TERM GOALS

This effort exists within a group dedicated to the use of autonomous underwater vehicles, and buoyancy-driven gliders in particular, to support Navy missions. The group generally uses the Seaglider™, developed at the Applied Physics Laboratory of the University of Washington (APL-UW), and develops or adapts instruments and glider behavior to support specific mission requirements. This group is informally called the Applied Seaglider™ Group, whose acronym, ASG, is also used to describe the Applied Seaglider™itself.

This report describes our efforts as part of the ONR Passive Autonomous Acoustic Monitoring (PAAM) program. The long-term goals of the PAAM program are as follows:

- Perform persistent and autonomous passive acoustic monitoring of a 500-1000 square nautical mile Navy exercise area for presence of marine mammals.
- Monitor for three weeks prior to, three weeks during, and three weeks after a typical exercise.
- Detect, classify and localize vocalizing marine mammals.
- Provide actionable information in a timely manner to the officer in tactical command to support marine mammal mitigation efforts.

OBJECTIVES

The primary objective is to build a passive acoustic detection and recording system for the Applied Seaglider™, with particular attention to the automated detection and classification of beaked whale vocalizations, and to quantify the system's performance with respect to the goals of the ONR PAAM program outlined above.

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APPROACH

We have chosen to focus on automated detection, classification, and recording of beaked whale vocalizations. Beaked whales vocalize at depths greater then 200m and use frequencies above 25kHz, as described by Zimmer *et al.* [**2008**], Johnson *et al.* [**2004**], and Zimmer *et al.* [**2005**]. The described characteristics are a good match with the ASG's depth range and physical dimensions.

Our approach has been as follows:

- Design and build a new acoustic detection and recording system with sufficient sampling rates, processing power, and storage capacity to enable ASG as an effective platform for beaked whale detection and recording.
- Collaborate with Drs. David Mellinger and Holger Klinck at Oregon State University (OSU) on beaked whale detection and classification algorithms.
- Conduct a series of bench and in-water tests to characterize system performance.
- Deploy locally in the presence of killer whales (*Orcinus orca*) as a proxy for beaked whales.
- Deploy off Kona (west) coast of island of Hawai'i on beaked whale survey missions.
- Deploy on instrumented Navy ranges (AUTEC and SCORE) in the presence of beaked whales to quantify detection performance.
- Participate in a Navy fleet-level demonstration at a site and time to be determined.

Key participants at APL-UW, in addition to the Principal Investigators shown above, are Bill Jump (hardware and system design engineer), Geoff Shilling (software engineer), Trina Litchendorf (ASG Lab), and Angie Wood (ASG Lab). A UW undergraduate engineering student, Mariah Gentry, provided essential data processing and analysis. Drs. Mellinger and Klinck at OSU have provided detection algorithms.

WORK COMPLETED

Three field deployments to detect and record beaked whale vocalizations were completed in FY2010:

- KONA I: Kona Coast, Island of Hawai'i
  27OCT2009 – 17NOV2009
  Seaglider™ S/N 022: 116 dives, 173.1GB acoustic data recorded

- KONA II: Kona Coast, Island of Hawai'i
  16MAR2010 – 26MAR2010
  Seaglider™ S/N 022: 61 dives, 82.6GB acoustic data recorded
  Seaglider™ S/N 023: 94 dives, 86.9GB acoustic data recorded

- AUTEC: Atlantic Undersea Test and Evaluation Center, Bahamas
  7JUN2010 – 11JUN2010
  Seaglider™ S/N 178: 35 dives, 47.5GB acoustic data recorded
  Seaglider™ S/N 179: 27 dives, 58.2GB acoustic data recorded

In preparation for these deployments, hardware modifications were completed. These included the ability to utilize both the 10V and 24V Seaglider™ battery packs to power the PAAM system, and the ability to host multiple USB memory sticks, mounted sequentially. These modifications significantly enhanced the endurance of the Seaglider™ PAAM system.

In addition, significant software upgrades were completed, including the installation of a refined detection algorithm provided by Drs. Mellinger and Klinck at OSU.

RESULTS

The KONA I and KONA II deployments were guided by Baird *et al.* [**2006**] and McSweeney *et al.* [**2007**].

Seaglider™ SG022's surfacing positions during the KONA I deployment are shown in Figure 1. The intent was to keep SG022 close to the 1500m isobath, the approximate midpoint of the habitats favored by *Mesoplodon densirostris* and *Ziphius cavirostris* (Baird [**2009**], private communication). The Seaglider™ executed repeated dives to 1000m; the PAAM board was set to detect and record below 500m.

The click detector was effective at distinguishing click trains from other signals. It was not proficient at separating naturally-produced sounds (beaked whale clicks) from man-made sounds (fathometers and fish finders). Detection statistics were skewed by the presence of these man-made sounds. Improvement in this aspect of the detector was a major motivation for KONA II.

The beaked-whale interclick interval (ICI) was a useful diagnostic, however. Cases where the near-realtime reporting of dive detection statistics indicated a a large number of energetic clicks with a high percentage within the typical beaked whale ICI range were examined manually after recovery of the Seaglider. A typical result is shown in Figure 2.

Results such as presented in Figure 2 demonstrated that the Seaglider™ PAAM system could successfully detect the presence of beaked whales, record their vocalizations in high enough fidelity to provide confidence in the detections, and report these detections in close to real time via Iridium satellite telephone. The 116 dives in this deployment also provided realistic power consumption values. Based on the typical 1000m dive depths, record-below 500m setting, with specified glider vertical velocities of 10 cm/s, and with the ability to draw off both Seaglider™ battery packs, missions of 58-days are possible. With the Seaglider™ extended-range battery packs (not flown in KONA I or KONA II), similar missions of 102 days are possible.

KONA I demonstrated the feasibility of a large part of the original PAAM program requirements: passive autonomous detection (and hence, since detection ranges are order a few kilometers, rough localization) of beaked whales, persistence of nine weeks, and near real-time notification.

The KONA II deployment of sg022 and sg023 had two goals: implement an improved detector to better discriminate between beaked whale clicks and man-made sounds, and to deploy two Seagliders™ to enhance detection opportunities.

Seagliders™ 022 and 023 were deployed out of Kailua-Kona on 16MAR2010. Unfortunately, sg023 developed a problem with its roll mechanism on 23MAR2010, and lost heading control when it was about 40nm offshore. SG022 continued to operate normally on its inshore patrol mission, as in KONA I. A rescue effort was mounted, and both gliders were recovered on 25MAR2010.
The KONA II deployment was long enough to verify the performance of the enhanced detector provided by Drs. Mellinger and Klinck of OSU. This detector was focussed more tightly on Blainville's Beaked Whale (*Mesoplodon densirostris*).

Complete sets of acoustic time series from KONA I and KONA II were sent to Drs. Mellinger and Klinck at OSU for analysis of detector performance. Their results will be reported separately.

The third deployment of FY2010 was of Seagliders™ 078 and 079 at the Atlantic Undersea Test and Evaluation Center (AUTEC), between 6JUN2010 and 11JUN2010. The Seagliders™ were deployed in AUTEC Weapons Range North. Personnel from Dave Moretti's group at NUWC/Newport ran the M3R (Marine Mammal Monitoring on Navy Ranges) software on the AUTEC hydrophone acoustic feeds for the duration of the deployment.

Tracks of the Seagliders™ in the AUTEC deployment are shown in Figures 3, 4, and 5. One Seaglider™ was commanded to stay in the vicinity of range hydrophone H4, at the center of the W1 high-resolution array, a known "hot spot" for beaked whales. The other Seaglider™ was commanded on a repeated east-west transect across the Tongue of the Ocean (TOTO) , who's western terminus was the area above range hydrophone H4.

A summary of the Seaglider™ click detections during the AUTEC deployment is given in Table 1 below. Note that these data summarize individual click detections, not individual encounters with animals, either singly or in groups.

Many encounters with beaked whales were reported, however, both by the Seagliders™ in near real time, and by the M3R system monitoring the range hydrophones. Preliminary estimates showed at least 25 separate Seaglider™ encounters (multiple click detections) with groups of beaked whales (Klinck [**2010**], private communication).

Raw acoustic time series from this deployment were provided to Drs. Mellinger and Klinck for analysis. We await a marked-up data set that documents the performance of their detector. We have the M3R detection data, and can then make a more quantitative analysis of our detection performance.

We are also still awaiting the completion of the NUWC/Newport data review and release process, so that we can get access to the acoustic time series data, in addition to the summary detection data we now have. That will allow completion of the quantative analysis by us and Drs. Mellinger and Klinck at OSU.

The three Seaglider™/PAAM open-ocean deployments in FY2010 demonstrated the ability to autonomously detect beaked whales on a system that meets the persistence and near real time notification goals of the original PAAM program.

Table 1. AUTEC PAAM Seaglider™ beaked whale detection summary.

	SG178					SG179				
Date June 2010 178/179	Dive	Dive Depth (m)	Detect Below (m)	Click Detect -ions	Detect -ions in ICI	Dive	Dive Depth (m)	Detect Below (m)	Click Detect -ions	Detect -ions in ICI
7JUN	1	49	5	191	19	1	51	5	8	0
7JUN	2	94	5	17	0	2	95	100	5	0
7JUN	3	183	5	13	3	3	458	100	8	1
7JUN	4	454	100	24	0	4	667	100	47	13
7/8JUN	5	663	100	129	5	5	916	300	23	1
8JUN	6	907	100	1763	331	6	912	300	9746	1996
8JUN	7	910	300	8511	1492	7	911	300	891	409
8JUN	8	913	300	2	0	8	915	300	965	474
8JUN	9	907	300	2	0	9	957	300	372	221
8/9JUN	10	902	300	4	0	10	1012	300	79	66
8/9JUN	11	904	300	70	24	11	979	150	1501	739
8/9JUN	12	909	300	3	0	12	959	150	64	17
8/9JUN	13	908	300	4	0	13	985	150	11	0
9/10JUN	14	1005	300	107	53	14	971	150	0	0
9/10JUN	15	992	300	718	465	15	1001	150		
9/10JUN	16	990	150	0	0	16	1002	150	13	5
9/10JUN	17	993	150	672	458	17	998	150	14	6
9/10JUN	18	991	150	1946	1258	18	1008	150	8	0
9/11JUN	19	671	150	412	106	19	1001	150	12	3
10/11JUN	20	994	150	0	0	20	998	150	43	0
10/11JUN	21	993	150	3	0	21	677	150	16	1
10/11JUN	22	995	150	14	2	22	675	50	3	1
10/11JUN	23	995	150	2634	1731	23	184	10	3	0
10/11JUN	24	995	150			24	184	10	0	0
10/11JUN	25	996	150	104	68	25	51	10	2	1
10/11JUN	26	991	150	27	13	26	53	10	93	65
11JUN	27	991	150	3	0	27	123	10	7	0

IMPACT/APPLICATIONS

The Seaglider™/PAAM detection and recording system has achieved an initial operational capability. Further testing on instrumented Navy ranges will refine the quantitative measures of performance. A fleet demonstration is anticipated in late-FY2011 or FY2012.

The Seaglider™/PAAM system has the frequency range, computational power and flexibility, and persistence to be capable of a wide range of passive acoustic detection and recording missions. It is especially suitable for higher-frequency applications, where hydrophones can be small and large acoustic aperture is not required. The multi-channel electronics and sophisticated computational capability make integrating lower-frequency systems feasible.

RELATED PROJECTS

There are many related projects to use passive acoustics to detect, classify, and monitor marine mammals; some are funded as part of ONR's broader PAAM program, some are supported elsewhere.

Dr. David Mellinger at OSU is directly funded by ONR under the PAAM program to provide beaked whale detection and classification algorithms. His annual report will cover these contributions in more detail.

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Figure 1. Seaglider™SG022 surfacing positions off the Kona coast of the island of Hawai'i, 27OCT2009 – 17NOV2009. SG022 operated between a series of waypoints along the 1500m isobath, and dove to a depth of 1000m.

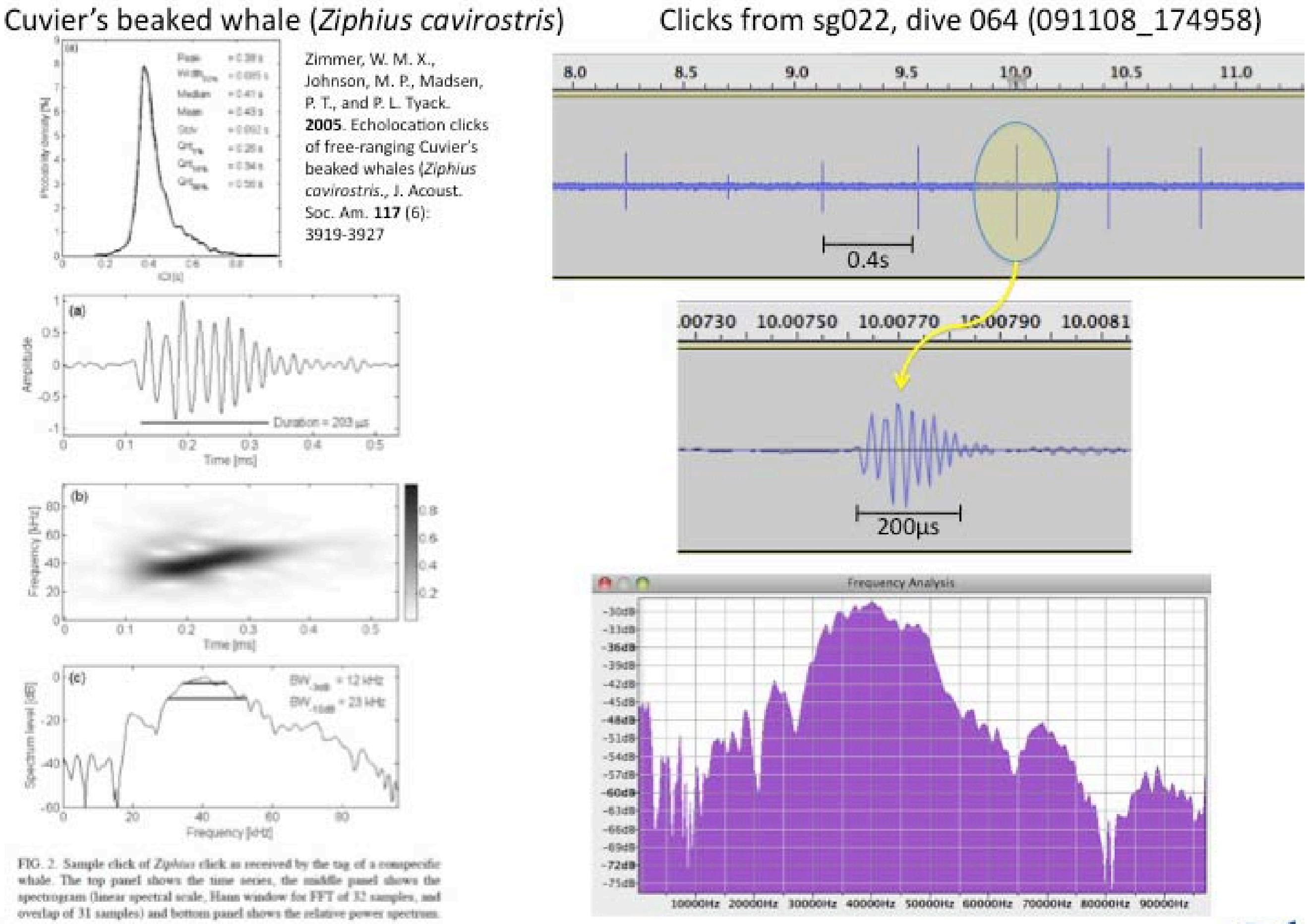

Figure 2 . Comparison of published Ziphius cavirostris click with click recorded by Seaglider™ PAAM system, at 912m near 19°35.05'N, 156°02.45'W, 8NOV2009.

Figure 3. Seaglider™ deployment at AUTEC: 7-11JUN2010, showing sg178 station keeping at H4, and sg179 running east-west transects from H4 to the eastern edge of the AUTEC hydrophone array.

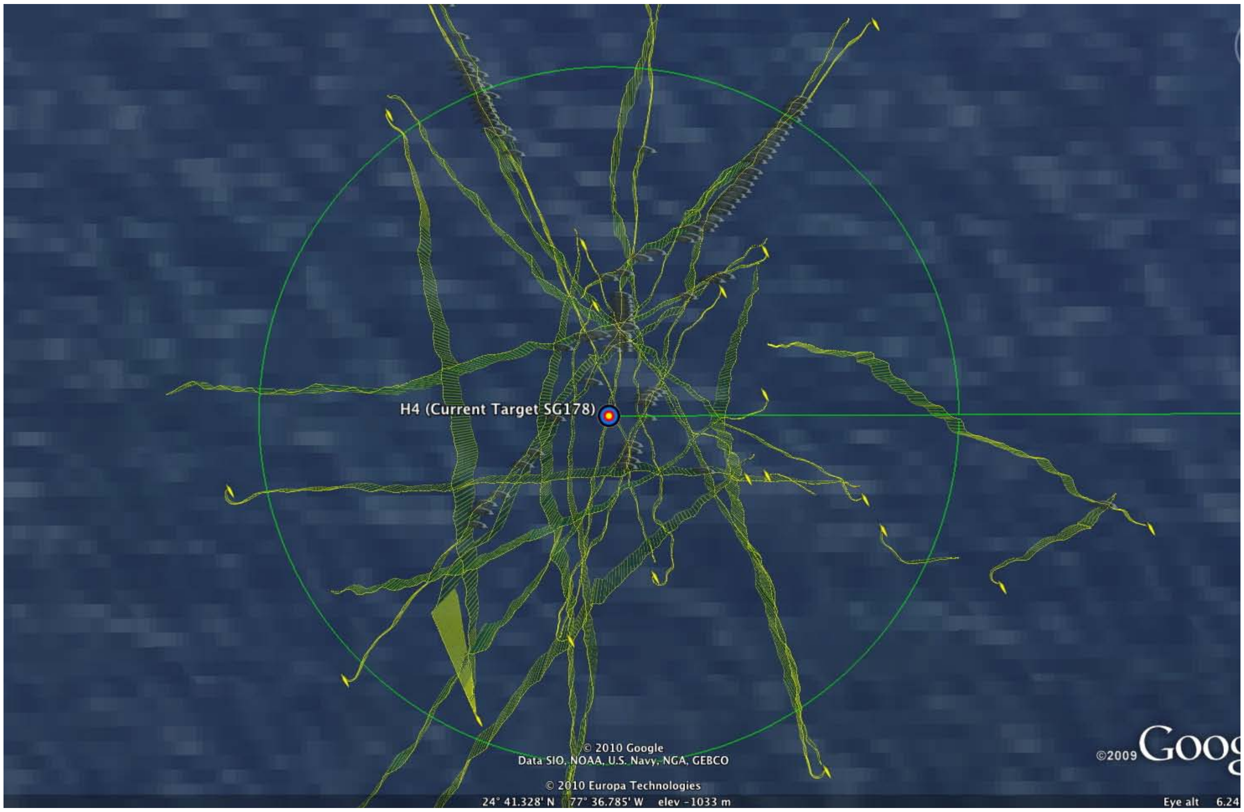

Figure 4. Blowup of SG178 station keeping dives at H4. Green circle has radius 1nm. Small beaked whale icons represent detections along the dive path.

Figure 5. Blowup of SG179 east-west transects at AUTEC. Green circles have a radius of 1nm. Small beaked whale icons represent detections along the dive path.